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Real-Time Control of Distributed Generation

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Distributed generation (DG) can be operated to control voltages and power flows within the distribution system. Improvements in distribution system reliability and overall power system efficiency can be realized. For load growth with short-lived peaks that occur during extreme weather, DGs may provide lower-cost solutions than other approaches to system capacity upgrades.

DG provides a means for increasing the capacity of existing distribution facilities. When considering increasing distribution system capacity, DGs can be an alternative to new substation addition and replacing existing equipment with larger ones. A DG installed at the distribution level releases capacity throughout the system, from transmission through distribution. Transmission system losses are eliminated, and distribution system losses are reduced.

Some customer facilities have DGs that are installed for back-up power. These DGs are employed during grid-power outages or periods of high-cost grid power. They are operated for only a small fraction of time over the year. Moreover, back-up DGs are usually oversized, which means that they can provide more power than their facility loads need. These DGs can be equipped with a set of devices that will enable them to seamlessly interconnect to the grid and be dispatched if needed. The available capacity from such DGs can then be used for utility purposes.

DGs across many circuits in distribution areas can be controlled from a single control point. That is, such DGs can be aggregated into a block of generation and made available for transmission system use.

Although specifically intended for DGs, the aggregate control may also include other means of capacity release. When equipped with the necessary control and interconnection instrumentation, capacitors can be involved in aggregate control also. Some loads may also participate in the aggregation process in the form of curtailable or interruptible load. The aggregate control handles the collection of all of these participating entities.

The total power made available to the transmission system by the aggregate control is exhibited as a capacity release. That is, it is not the power injected into the transmission system from the distribution side, rather it is less power drawn by the distribution side. In the discussion to follow, the phrases DG power by aggregate control and capacity release by aggregate control are used interchangeably.

The aggregate control of DGs may serve a number of purposes. For instance, aggregated DGs can be activated if the transmission system or the distribution utility is having supply emergencies. Thus, DG aggregation provides a means to increase operating reserve. DGs can also help utilities manage energy purchases during times when the transmission grid electricity price is excessively high.

In the next section, local control for common DGs is discussed first. Next, controlling a group of DGs as an aggregate is addressed. Then, the DG as part of a hierarchical control system for controlling voltages and system power flows is investigated. Finally, load estimation for real-time DG control and also for forecasting aggregate control of DGs is presented.

24.1 Local Site DG Control

A DG operates basically in two modes in regard to being connected to the utility grid. In parallel mode, the DG remains connected to the grid. Hence, both the DG and the grid provide power for the local load in the customer facility (or DG site). In stand-alone (isolated or island) mode the DG is the sole power source to the local loads. In this section, consideration will be given only to DGs operating in parallel with the grid.

There are several forms of control for parallel DG. In one form of control, a local controller maintains a constant kW and kVar generation. In most cases, the local load is greater than the DG. Therefore, the power mismatch is supplied by the grid.

In another form of local control, the DG is controlled in order to maintain a constant power flow at the point of common coupling (PCC)—the point where the DG site interfaces with the grid, which is basically the metering point. The power flow maintained might be from the grid into the DG site (import) or from the site into the grid (export). As the local load varies, the local controller acts to change the kW and kVar generation at the DG in an attempt to keep the power flow constant at the PCC.

The most common DGs in service utilize synchronous machines. They prevail in grid-scale power exchanges between the utility and DG sites. Internal combustion (IC) engines and combustion turbines are the main prime movers for the synchronous generators. IC engines are much more common. Diesel fuel and natural gas are chosen for powering these engines.

The control of a synchronous machine is achieved by adjusting the fuel flow into the engine and the excitation of the generator. The fuel flow control by the governor determines the horsepower (kW) developed on the shaft of the engine. In a parallel DG, the shaft speed must be maintained very close to system frequency. The governor uses the kW set-point signal from the local controller and the speed signal from the DG output. The governor adjusts the fuel control to cause the kW output of the DG to match the kW set point that is set by the local controller.

The excitation control achieved by the voltage regulator determines terminal voltage and kVar output of the generator. Parallel DGs are required not to actively participate in regulating voltage at the PCC where the grid is supposed to set the voltage. Therefore, the excitation control is used to adjust kVar generation only. Rather than a kVar set point, a power factor (pf) set point is used for the excitation control. The local controller feeds the pf set point to the regulator. The regulator then adjusts the excitation to match the pf measured at the DG to the provided pf setting.

Basic functionality of the control system for parallel-connected DGs can be seen in [Fig. 24.1](#). For simplicity, it is assumed that the customer facility has only one DG. The local control receives the desired kW and kVar generation set points from an upper-level controller. The strategy can be a constant kW and kVar generation level for the DG or a constant kW and kVar flow at the PCC. Based on the control strategy, the local controller sends the required set points to the controller of the DG. An operator can supervise the control process and intervene as needed.

24.2 Hierarchical Control: Real-Time Control

The hierarchical DG control consists of three levels and is illustrated in [Fig. 24.2](#). The control functionality is used for two purposes: (1) for real-time DG control and (2) for forecasting future generation.

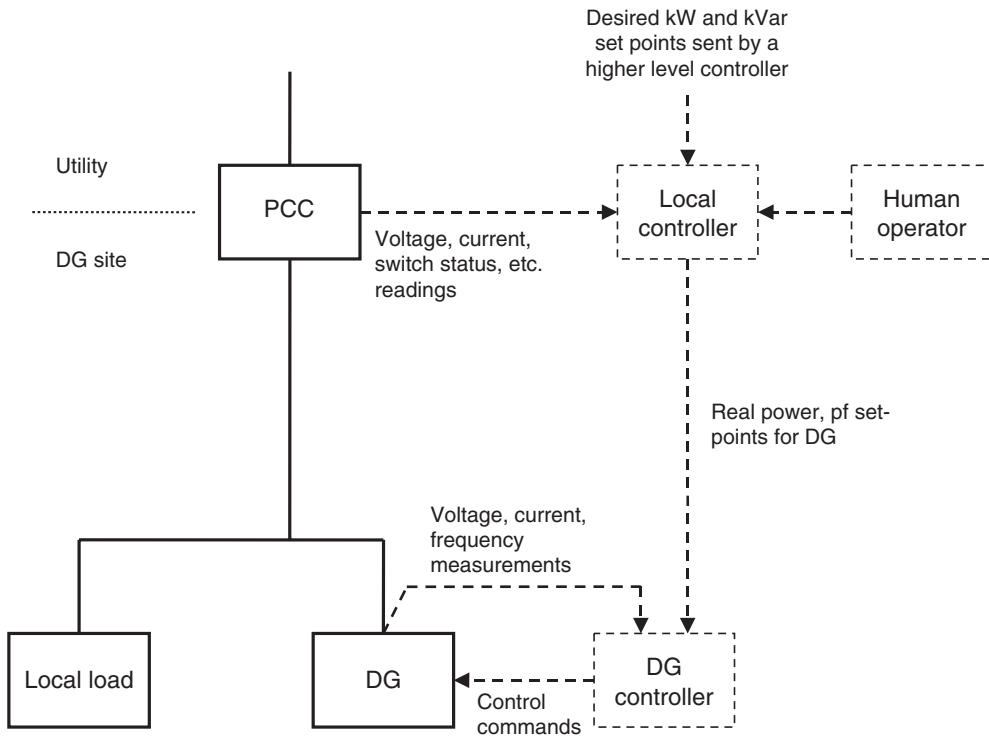


FIGURE 24.1 Block diagram for local control of a parallel DG at a customer site.

The aggregate control at level 3 shown in Fig. 24.2 groups DGs together from many distribution circuits within a distribution service area. The aggregate control talks to both a transmission system entity (let us refer to this entity as the independent system operator, ISO) at a higher level and the circuit controls below at level 2. Each circuit might have a number of DG sites from which the circuit can import power. Each such DG site has a local controller (level 1) that can handle the import/export processes as explained in the previous section.

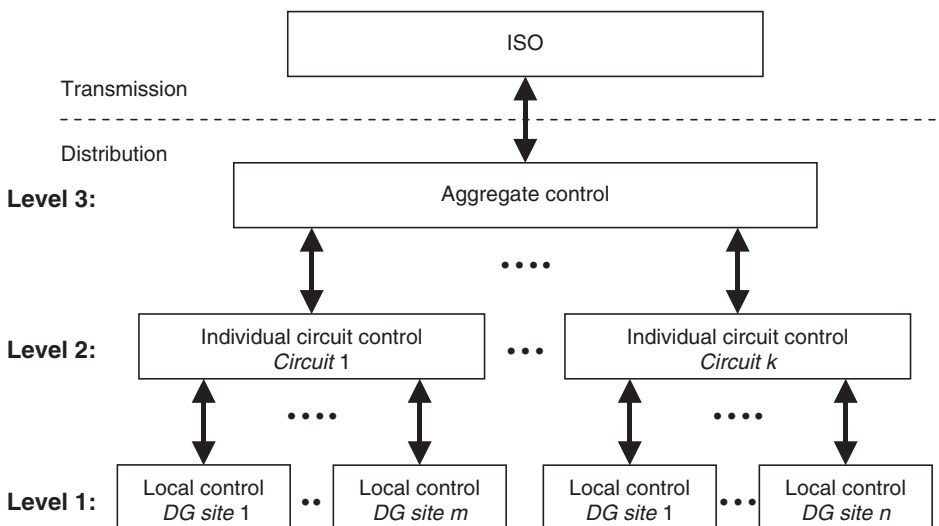


FIGURE 24.2 Hierarchical view of the control of aggregated DGs.

The challenge of DG control is to implement the control without having to install measurement or monitoring equipment throughout the many miles of the distribution circuits. Each circuit control at level 2 has a model of the corresponding circuit, which includes such data as any existing circuit measurements and historical load measurements. Given weather and circuit conditions, the circuit control can make use of the available circuit model to estimate the power flows rather than measure the flows via instrumentation that would have to be installed throughout the circuit. This will be discussed further.

In essence, the aggregate control evaluates the DG power present at its lower levels and informs the ISO about the DG power that can be made available for transmission system use. After some negotiations, the ISO informs the aggregate control of the power it needs. The aggregate control then talks to the circuit controls in an attempt to provide the requested power in the best way possible. Data traffic among the layers of the control hierarchy in Fig. 24.2 can be seen in Fig. 24.3. Note that in order to simplify the discussion only a partial view of the data flow is presented. The view shown considers one circuit and one DG site in that circuit. One can extend this view to understand the data flow for the general case where multiple circuits with multiple DGs would be involved.

The data flow will be examined from two perspectives: flow from lower to higher layers and flow from higher to lower layers. The nomenclature used in Fig. 24.3 is as follows:

- P_{dg-mr} : must-run real power (kW) generation from DG site
- Q_{dg-mr} : must-run reactive power (kVar) generation from DG site
- P_{dg-sp} : desired kW generation from DG site
- Q_{dg-sp} : desired kVar generation from DG site
- P_{ckt-mr} : must-run kW generation needed by circuit
- Q_{ckt-mr} : must-run kVar generation needed by circuit
- $P_{ckt-max}$: maximum kW generation available from circuit
- $Q_{ckt-max}$: maximum kVar generation available from circuit
- $P_{ckt-des}$: desired kW generation from circuit
- $Q_{ckt-des}$: desired kVar generation from circuit
- P_{tot-mr} : total must-run kW generation needed by all circuits
- Q_{tot-mr} : total must-run kVar generation needed by all circuits

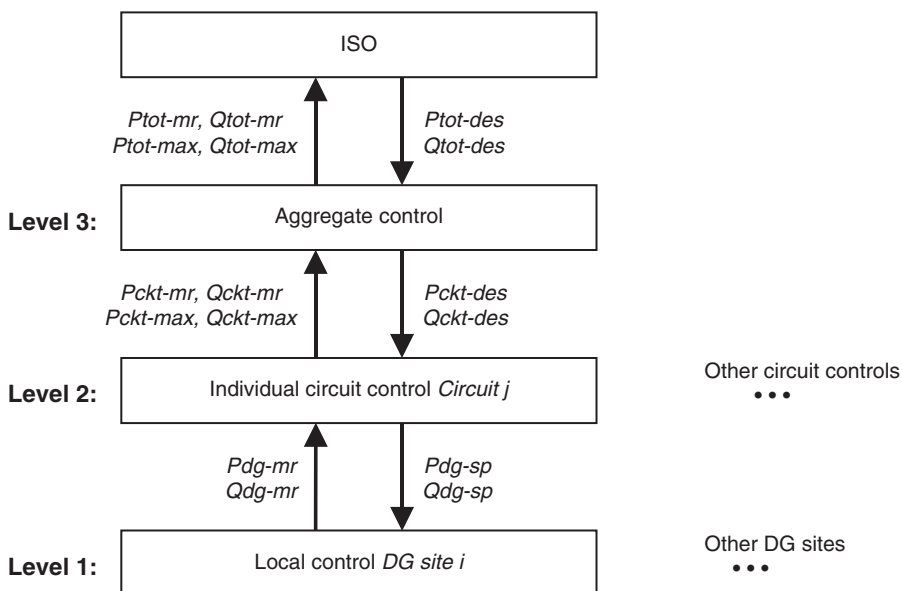


FIGURE 24.3 Data flow among ISO, aggregate controller, controller of a particular *Circuit j*, and controller of a particular *DG site i* in *Circuit j*.

$P_{tot-max}$: total kW generation available from all circuits

$Q_{tot-max}$: total kVar generation available from all circuits

$P_{tot-des}$: total desired kW generation needed by ISO from aggregate DG control

$Q_{tot-des}$: total desired kVar generation needed by ISO from aggregate DG control

24.2.1 Data Flow to Upper Layers

As mentioned earlier, level-2 circuit controllers have their corresponding circuit models, which are used to estimate power flows throughout the circuits. Given weather and circuit conditions such as voltage and current measurements taken at the start of circuit, the circuit controllers evaluate flows and voltages for the circuits. Consider for example *Circuit j* shown in level 2 in Fig. 24.3. The circuit controller of *Circuit j* examines voltages and loadings in the circuit. If there exist any circuit problems such as under-voltage or overloaded locations in the circuit, then the circuit controller attempts to use the controllable DGs in the circuit to eliminate the problems. If employing the DGs helps to solve the circuit problems, then the DG kW and kVar generation levels at which the problems disappear are recorded. Such generation quantities are labeled as “must run,” which means that the circuit itself needs that DG for solving its own problems.

Consider *DG site i* at level 1 in Fig. 24.3. P_{dg-mr} and Q_{dg-mr} represent the kW and kVar amounts that *DG site i* needs to produce in order to remove the problems that *Circuit j* will experience. P_{dg-mr} and Q_{dg-mr} will be zero if no circuit problems occur when the *DG site i* produces no power.

Each circuit controller at level 2 sums up must-run generation. Each circuit controller also calculates the total available generation within the circuit. Must-run and maximum generation amounts are passed to the aggregate control at level 3. In Fig. 24.3, P_{ckt-mr} , Q_{ckt-mr} , $P_{ckt-max}$, and $Q_{ckt-max}$ indicate must-run and maximum generations from *Circuit j*. Note that $P_{ckt-max}$ and $Q_{ckt-max}$ may also include curtailable load and reactive power available from capacitors installed in *Circuit j*. The *Circuit j* controller at level 2 may also know the type and operating characteristics of the DGs. Therefore, $P_{ckt-max}$ and $Q_{ckt-max}$ may actually be further subdivided into available base-load generation and available load-following generation.

The aggregate control at level 3 sums both the totals of must-run generation and the maximum available generation across the individual circuit controllers at level 2. These sums are communicated to the ISO, as indicated by P_{tot-mr} , Q_{tot-mr} , $P_{tot-max}$, and $Q_{tot-max}$ in Fig. 24.3. Generation costs may also be communicated to the ISO, which is not considered here.

24.2.2 Data Flow to Lower Layers

The aggregate control negotiates with the ISO. When the negotiation is complete, the ISO informs the aggregate control of the total desired real and reactive generation. $P_{tot-des}$ and $Q_{tot-des}$ in Fig. 24.3 indicate the kW and kVar amounts requested by the ISO, respectively.

The aggregate control takes the total amount of desired generation and divides it among the DGs in the circuits under its control. $P_{ckt-des}$ and $Q_{ckt-des}$, for instance, represent kW and kVar generation that the aggregate control allocates for *Circuit j* to provide. A circuit controller at level 2 addresses control for all DG sites located in the corresponding circuit. Each circuit controller determines the generation sharing among the individual generators, based upon economic and reliability considerations. Thus, kW and kVar generation levels for all DGs under a circuit are calculated and communicated to the corresponding local controllers at DG sites. These kW and kVar values become the set points for the generator controllers. For instance, P_{dg-sp} and Q_{dg-sp} in Fig. 24.3 are the kW and kVar set points for the DG at *DG site i* in *Circuit j*.

24.3 Control of DGs at Circuit Level

Basic functions used in circuit-level control are depicted in Fig. 24.4. The direction of arrows in the figure is interpreted such that what is at the tail-side of an arrow is available for use by what is at the head

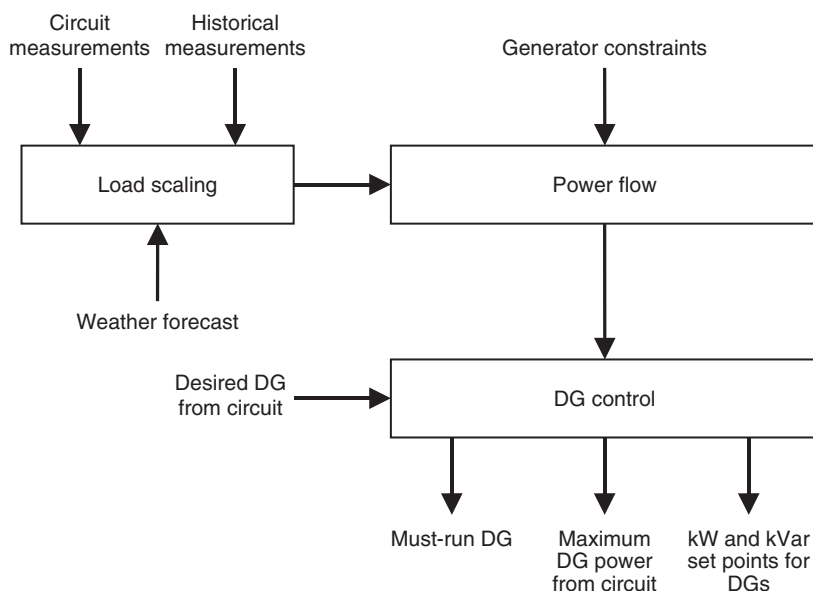


FIGURE 24.4 Level-2 DG control functions.

of the arrow. For instance, the arrow between *Power Flow* and *DG Control* indicates that *Power Flow* is used by the *DG Control* task. That is, *DG Control* can run *Power Flow* and obtain power flow results. Similarly, it can be seen that circuit measurements are made available for use in the load scaling.

All the functions shown in Fig. 24.4 share the same circuit model and circuit data. Exchange of results among these functions takes place through the common circuit model. The circuit model and data include the following:

- Topology information of the circuit
- Type, status, rating, configuration, impedance, and/or admittance of the components present in the circuit
- Location and class of loads connected throughout the circuit
- Historical load measurements
- Load research data for the various classes of loads

Typically, measurements are taken at a very limited number of locations such as at the start of the circuit and DG sites. Therefore, the main task is to use the circuit model and the available measurements to estimate the flows in the circuit. That is, the majority of flows are determined by calculations instead of measurements obtained via data acquisition systems.

The most common scenario concerning control is as follows. Real-time current and voltage measurements taken at the start of the circuit are fed into the circuit model. Real-time kW and kVar measurements taken at the DGs are also fed into the model. *Power Flow* then calculates voltages and currents throughout the circuit. Since the load data (location, class, historical measurements, and load research data such as load curves, coincidence, and diversity factors) are already available, *Power Flow* uses *Load Scaling* for matching the calculated flows to the measurements. *Load Scaling* adjusts the circuit loads until the calculated flows match the measured flows. This is thus an estimation process for the loads that result in the measured flows.

In case real-time circuit measurements are not available, historical measurements and weather data are used to estimate loading. From this information, the flows at the start of circuit can be estimated. Then the estimated flows are used as if they were measurements at the start of the circuit, and *Load Scaling* again adjusts load sizes so that the estimated and measured flows match.

Once the circuit flows are estimated, *DG Control* can check to see if there are any circuit problems such as overloaded equipment and/or locations with voltages below specified limits. If problems exist, *DG Control* runs power flow calculations and uses the controllable DGs to attempt to eliminate the problems. If the problems are removed, the generation levels required are referred to as must-run generation.

In another scenario, suppose that initially there are no problems in the circuit. However, the real-time kW and kVar DG measurements show that some DGs are running. In this case, *DG Control* tries reducing the generation to check if the no-problem condition can be obtained with less DG. If so, the reduced generation levels will be reported as must run.

Besides the must-run generation, *DG Control* also calculates the total power that can be dispatched by the circuit control. Circuit loading and generator constraints are used in this process. When DGs are dispatched, circuit losses and voltage profiles in the circuit are affected. Therefore, when looked at from the transmission side, the maximum power flow change that the DGs can achieve is greater than their rated capacities. The additional capacity achieved is due to reduced losses in the circuit and DG effects on circuit voltage profiles.

The explanation given in the preceding paragraphs is from the point of view of what happens in level 2 when data flows upward in the control hierarchy. The result of this flow is must-run generation levels and additional capacity release that can be provided for the transmission side. On the other hand, when the data flows downward from level 3, the aggregate control informs the circuit control of how much DG power is desired from the circuit. This desired power quantity is given as an input parameter to *DG Control* as shown in Fig. 24.4. *DG Control* then evaluates how the desired power can be realized from the participating DGs in the circuit. This is basically an assignment problem: How much power should each generator produce so that the desired total power can be obtained in the most effective way possible? Generator constraints, fuel costs, generator operating characteristics, circuit-loss effects, reliability effects, and other parameters can be considered in this assignment process. At the end, the settings for kW and kVar generation that need to be supplied from individual DG sites are determined and sent to local controllers.

24.3.1 Estimating Loading throughout Circuit

The control of the DGs at the circuit level constitutes a major computational element in the control hierarchy. As stated earlier, the control primarily uses estimates of circuit conditions rather than measurements. Estimating the loading of customers throughout the circuit model plays a central role in the success of the control. Because system load is usually monitored at only a few points in the circuit, determining circuit loads accurately is a challenging process. In general, load is monitored at substations, major system equipment locations, and major customer (load) sites. Besides such load data, the only load information commonly available is billing-cycle customer kilowatt-hour (kWh) consumptions. The estimation of load has features described next.

Historical load measurements: Historical load measurements consist of monthly kWh measurements or periodic (such as every 15-minute or hourly) kW/kVar measurements obtained at customer sites. These measurements are used in the estimation of loading at each customer site in the circuit model.

Load research statistics: With the help of electronic recorders, utilities can automatically gather hourly sample load data from diverse classes of customers. This raw data (load research data) is then analyzed to obtain load research statistics. The purpose of load research statistics is to convert kWh measurements to kW and kVar load estimates. Load research statistics consist of the following elements:

- *Kilowatt-hour parsing factors* are defined as a function of customer class. They represent the fractional annual energy use as a function of the day of the year. Thus, they vary from 0 to 1. They are used to split a kWh measurement made across monthly boundaries into estimates of how much of the measurement was used in each month.
- *kWh-to-peak-kW conversion coefficients* (referred to as C-factors) are used to convert kWh measurements for a customer to peak-kW estimates. The C-factor is calculated as a function of

class of customer, type of month, type of day, and weather condition. C-factor curves are typically parameterized by the customer class, type of day, and weather condition, and plotted against the month of year.

- *Diversity factors* are used to find the aggregated demand of a group of customers. It is defined as the ratio of the sum of individual noncoincident customer peaks in the group to the coincident peak demand of the group itself. The diversity factors are greater than unity. They are defined as function of class of customer, type of month, type of day, weather conditions, and number of customers. Diversity factor curves are typically parameterized by the customer class, type of day, type of month, and weather condition, and plotted against number of customers.
- *Diversified load curves* are parameterized by class of customer, type of month, type of day, and weather conditions. They show the expected energy use for each hour of the day. Diversified load curves may be used to estimate loading as a function of the hour of day. Diversified load curves may be normalized by dividing each point on the diversified load curve by the peak of the diversified curve itself.
- *Temperature/humidity load sensitivity coefficients* are defined as a function of class of customer. They are used to scale loads to take into account temperature/humidity load sensitivities. They are calculated by correlating load research data with the weather conditions that existed at the time the load research measurements were made.

Start-of-circuit measurements: Start-of-circuit measurements generally consist of voltage magnitude, current magnitude, and/or power flows. They are used to affect scaling of estimated loads throughout the distribution circuit model such that the power flow solution matches the start-of-circuit measurements.

Examples of load research statistics for a residential class of customer are shown in Figs. 24.5 through 24.9. Figure 24.5 illustrates a parsing-factor curve as a function of the day of the year. The parsing factor may be used together with monthly kWh measurements to estimate the energy usage between any two days of the year.

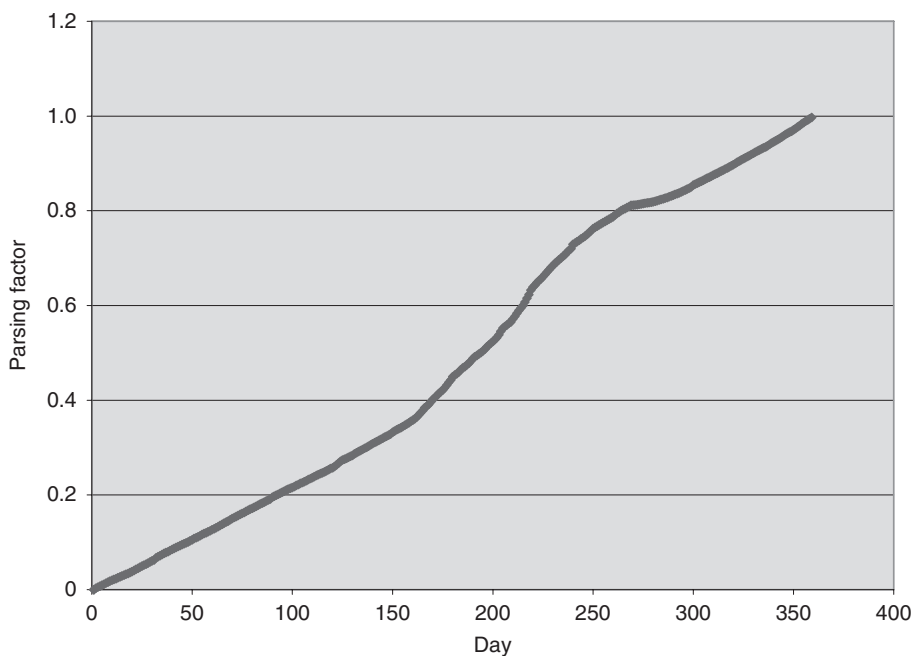


FIGURE 24.5 A representative parsing-factor curve for residential customer.

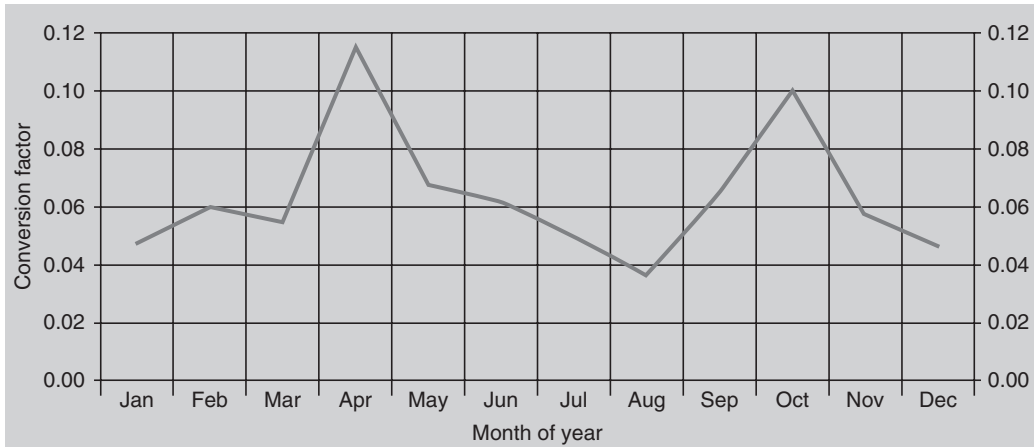


FIGURE 24.6 kWh-to-peak-kW conversion coefficients for residential class for weekdays at normal weather conditions.

Figure 24.6 illustrates a representative C-factor curve for residential customers for weekdays at typical weather conditions, where the C-factor is plotted as a function of month. Values read from this curve may be used to convert kWh measurements into kW-peak estimates for weekdays.

Figure 24.7 illustrates a diversified load curve for weekdays during February at normal temperatures as a function of hour of day.

Figure 24.8 illustrates a diversity factor curve for weekdays during February at normal temperatures as a function of the number of customers.

Figure 24.9 represents variation of load scaling factors for residential customers as a function of weather condition. Note that weather condition incorporates not only the temperature, but also other factors such as humidity and wind speed. Variations in these quantities are compounded into a single index.

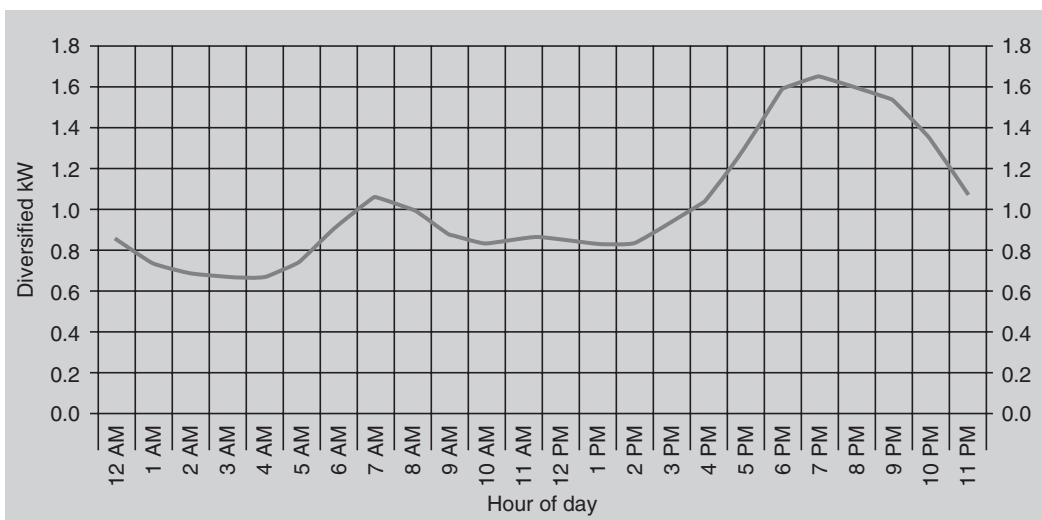


FIGURE 24.7 Diversified load curve for residential class for weekdays during February at normal weather conditions.

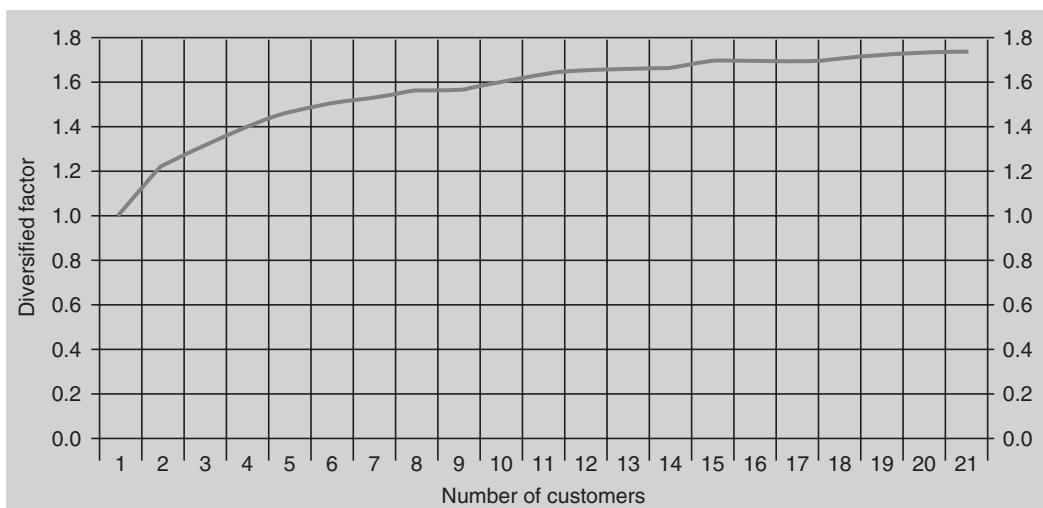


FIGURE 24.8 Diversity factor curve for residential class for weekdays during February at normal weather conditions.

As an example of calculating a load estimate at a point in a circuit, assume the following (where for simplicity, weather considerations have been neglected):

- Below the point selected, the circuit is radial.
- It is desired to estimate the peak-kW of the group of customers for a weekday in February. It is also desired to calculate the combined kW load of the two customers at 2 pm on a weekday in February.

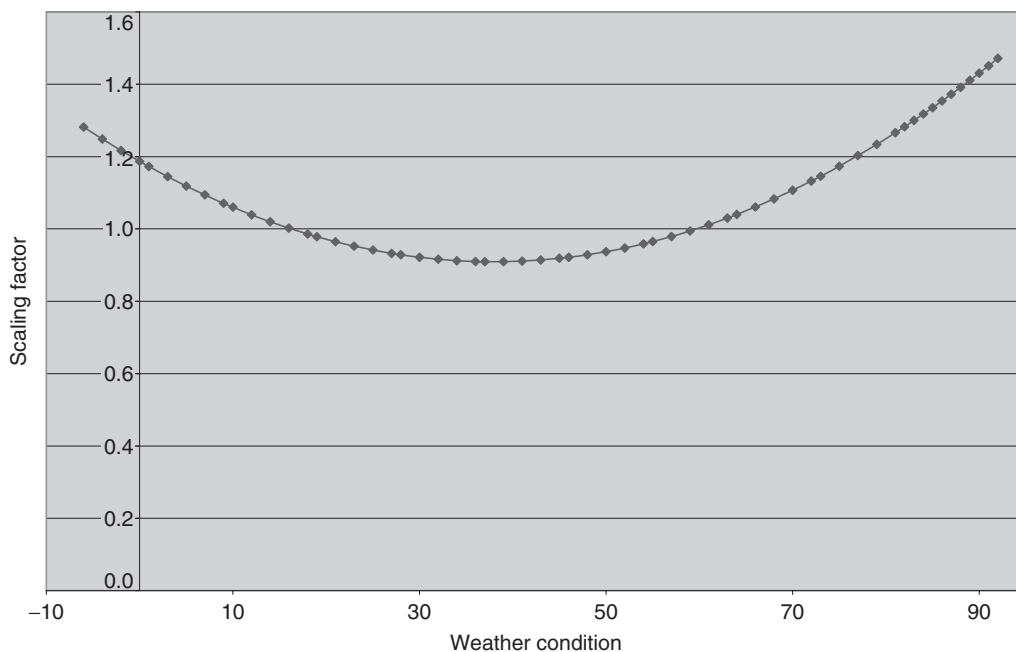


FIGURE 24.9 Representative variation of load scaling factors for residential customers as a function of weather condition.

- There are only two customers of the same load research class, say Class R, fed from the selected point.

Assume that each customer only has monthly kWh measurements as given by:

$KWH_{m1}(Jan18, Feb16)$ = Measured kWh usage of first customer between the dates January 18 and February 16.

$KWH_{m1}(Feb17, Mar17)$ = Measured kWh usage of first customer between the dates February 17 and March 17.

$KWH_{m2}(Jan20, Feb17)$ = Measured kWh usage of second customer between the dates January 20 and February 17.

$KWH_{m2}(Feb18, Mar19)$ = Measured kWh usage of second customer between the dates February 18 and March 19.

The first step is to estimate the energy usages of each customer during the month of February. Note that the recorded measurements do not directly reflect the February usages. Parsing factors provide the ability to estimate the February energy usage from the two measurements available.

Let $p(MonX)$ represent the parsing-factor value for customers of Class R for day X in month Mon. Then using the kWh measurements given above, the estimated kWh energy use of Customer 1 during February is calculated as follows:

$$KWH_{e1}(Feb1, Feb16) = KWH_{m1}(Jan18, Feb16) \times \frac{p(Feb16) - p(Feb1)}{p(Feb16) - p(Jan18)}$$

$$KWH_{e1}(Feb17, Feb28) = KWH_{m1}(Feb17, Mar17) \times \frac{p(Feb28) - p(Feb17)}{p(Mar17) - p(Feb17)}$$

$$KWH_{e1}(Feb) = KWH_{e1}(Feb1, Feb16) + KWH_{e1}(Feb17, Feb28)$$

where $KWH_{e1}(Feb)$ = Estimated kWh usage of Customer 1 during February.

$KWH_{e1}(Feb1, Feb16)$ = Estimated kWh usage of Customer 1 between February 1 and February 16.

$KWH_{e1}(Feb17, Feb28)$ = Estimated kWh usage of Customer 1 between February 17 and February 28.

A similar calculation can be performed to estimate the kWh usage of Customer 2 during February:

$$KWH_{e2}(Feb1, Feb17) = KWH_{m2}(Jan20, Feb17) \times \frac{p(Feb17) - p(Feb1)}{p(Feb17) - p(Jan20)}$$

$$KWH_{e2}(Feb18, Feb28) = KWH_{m2}(Feb18, Mar19) \times \frac{p(Feb28) - p(Feb18)}{p(Mar19) - p(Feb18)}$$

$$KWH_{e2}(Feb) = KWH_{e2}(Feb1, Feb17) + KWH_{e2}(Feb18, Feb28)$$

The next step is to estimate the peak kW demand by the two customers together. For this, we use the C-factors and diversity factors (d) from the load research statistics. Consider the following:

$C(\text{weekday}, Feb, R)$ = The kWh-to-peak-kW factor value for customers of Class R for weekdays during February.

$d(\text{weekday}, Feb, R, 2)$ = The diversity-factor value for two customers of Class R for weekdays during February.

$KW_{\text{peak}}(\text{Sum})$ = Sum of the individual kW peaks (noncoincident peaks) for the two customers.

$KW_{\text{peak}}(\text{Group})$ = The group peak (coincident peak) for the two customers.

Then,

$$\begin{aligned} KW_{\text{peak}}(\text{Sum}) &= C(\text{weekday}, \text{Feb}, R) \times (KWH_{e1}(\text{Feb}) + KWH_{e2}(\text{Feb})) \\ KW_{\text{peak}}(\text{Group}) &= KW_{\text{peak}}(\text{Sum}) / d(\text{weekday}, \text{Feb}, R, 2) \end{aligned}$$

This is the first answer that was sought, which is the estimated peak of the group of customers on a weekday in February. The diversified load curve corresponding to the given conditions can be referred to for finding the time point (hour) of day at which the peak would occur. One can examine kW demands at any other time points, say at 2 pm, as well. The normalized diversified load curve is used for this purpose. The normalized curve has the maximum value of unity at its peak-kW time point. To estimate the load of the two customers at 2 pm on a weekday in February, let $k(2 \text{ pm}, \text{weekday}, \text{Feb})$ be the normalized diversified load curve value for customers of Class R at 2 pm for weekdays during February. Then, the estimated load at 2 pm, $KW_e(\text{Group}, 2 \text{ pm}, \text{weekday}, \text{Feb})$ is given by

$$KW_e(\text{Group}, 2 \text{ pm}, \text{weekday}, \text{Feb}) = k(2 \text{ pm}, \text{weekday}, \text{Feb}) \times KW_{\text{peak}}(\text{Group})$$

24.3.2 Siting DGs for Improving Efficiency and Reliability

Along with voltage and power flow control, DGs can be placed within the distribution system for simultaneously improving efficiency and reliability. That is, there are many locations within a circuit from which a DG can implement some desired voltage or flow control, and of these many locations, the location that results in the optimum improvement in efficiency and/or reliability can be selected.

Within a system of circuits, the circuits can be reconfigured via switching operations and DG can be shifted from one circuit to another in order to implement some desired control. With such switching operations, the DG does not necessarily need to be operated as an island. That is, a DG that is connected to an unenergized circuit may be switched to an energized circuit, and then brought on line. Thus, a DG can be placed to serve a number of circuits, and can be looked at as increasing both efficiency and reliability for the system of circuits.

For a single circuit or a system of circuits, the DG site placement for best reliability is generally not the same as the placement for best efficiency. Percent changes in system reliability and efficiency can be used to determine desirable locations from a limited set of geographical locations where the DG may be placed.

To obtain good locations for efficiency and/or reliability improvements, exhaustive searches and/or optimization methods may be applied. The exhaustive search approach often works well because there are generally only a very limited number of physical sites for placing DGs. This is due to constraints placed on the siting from community impact and available land considerations.

The method that is used to site the DG should take into account the time-varying loading of the circuits involved. Placing a DG based upon just peak loading conditions will generally not result in the best reliability or efficiency when the entire time-varying load pattern is considered.

24.4 Hierarchical Control: Forecasting Generation

The load estimation discussed above is combined with a weather forecast and used to forecast system loading on an hourly basis. This load forecast is used to provide a generation schedule to the ISO, and is typically performed for the 24 hours of the next day. Forecasting the next day's generation uses functionality found in levels 2 and 3 of the hierarchical control shown in [Fig. 24.2](#).

The load forecast is used to predict a schedule of must-run generation located in the distribution system. The forecast is also used to provide the ISO with the amount of base load and load following generation available at the distribution level. The amount of available generation is a function of the circuit loading. DGs provide the possibility of causing the power to flow from the distribution system to the transmission system. Since typical distribution systems are not designed to handle reverse power flows, including reverse fault currents, IEEE 1574 recommends that DGs be operated at a generation

level that is 25% or less of existing circuit loading. This is taken into account when calculating the maximum amount of generation available from the distribution system.

In the forecast, DG that is just for standby must be treated specially. The load that the standby generation serves is what must be reported to the ISO as a capacity release, and not the capability of the standby generation itself. Load research statistics coupled with the weather forecast are used to estimate the hourly variation of the load that is served by the standby generation. It is this release of load estimate that is then reported to the ISO.

References

- Broadwater, R.P., Sargent, A., Yarali, A., Shaalan, H.E., and Nazarko, J., Estimating substation peaks from load research data, *IEEE Transactions on Power Delivery*, 12(1), 451–456, 1997.
- Daley, J.M. and Siciliano, R.L., Application of emergency and standby generation for distributed generation. I. Concepts and hypotheses, *IEEE Transactions on Industry Applications*, 39(4), 1214–1225, 2003.
- IEEE Std. 1547-2003, *Standard for Interconnecting Distributed Resources with Electric Power Systems*.
- NREL SR-560-34779, *Aggregation of Distributed Generation Assets in New York State*, National Renewable Energy Laboratory (NREL), Colorado, 2004.
- Sargent, A., Broadwater, R.P., Thompson, J.C., and Nazarko, J., Estimation of diversity and kWhr-to-peak-kW factors from load research data, *IEEE Transactions on Power Systems*, 9(3), 1450–1456, 1994.
- Westinghouse Electric Cooperation, *Electric Utility Engineering Reference Book—Distribution Systems*, vol. 3, Westinghouse Electric Cooperation, East Pittsburgh, PA, 1965.

